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An Appraisal-Driven Componential Approach to the Emotional Brain

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Abstract

This article suggests that methodological and conceptual advancements in affective sciences militate in favor of adopting an appraisal-driven componential approach to further investigate the emotional brain. Here we propose to operationalize this approach by distinguishing five functional networks of the emotional brain: (a) the elicitation network, (b) the expression network, (c) the autonomic reaction network, (d) the action tendency network, and (e) the feeling network, and discuss these networks in the context of the affective neuroscience literature. We also propose that further investigating the “appraising brain” is the royal road to better understand the elicitation network, and may be key to revealing the neural causal mechanisms underlying the emotion process as a whole.

Keywords

affective neuroscience, appraisal, brain, emotion

Since its emergence as an integrated discipline in the 1990s (e.g., Davidson & Sutton, 1995; Panksepp, 1991), affective neuroscience has led to novel and important contributions to our understanding of the emotional brain (see Armony & Vuilleumier, 2013). Benefiting from the converging behavioral, computational, and neural evidence that is characteristic of affective neuroscience, the major theories of emotion—in particular the basic, bi/tri-dimensional, and appraisal approaches—are progressively being considered within the scope of affective neuroscience (e.g., Adolphs, 2017; Anderson & Adolphs, 2014; Brosch & Sander, 2013; Grandjean, Sander, & Scherer, 2008; Hamann, 2012; Koelsch et al., 2015; Kragel & LaBar, 2016; Kragel, Sander, & LaBar, in press; Lindquist, Wager, Kober, Bliss-Moreau, & Barrett, 2012; Nummenmaa & Saarimäki, in press; Pessoa, 2010; Posner et al., 2009; Sander, Grandjean, & Scherer, 2005; for review see Sander, 2013). For instance, it has been suggested that specific brain regions are particularly related to individual emotions (e.g., the amygdala with fear; see Hamann, 2012, for discussion), families of emotions (e.g., the hippocampus for attachment-related emotions; see Koelsch

et al., 2015, for discussion), valence/arousal processing (e.g., the mesolimbic system for valence processing and the reticular formation for arousal; see Posner et al., 2009, for discussion), or appraisals (e.g., the amygdala for relevance detection; see Brosch & Sander, 2013, for discussion).

The current perspective article is guided by two theoretical traditions in emotion research, the appraisal and the componential perspectives, and focuses on how they can interact with affective neuroscience research in order to shed new light on how one may conceptualize the functional organization of the emotional brain. More specifically, we present here an appraisal-driven componential approach to the emotional brain. First, we suggest that as soon as one considers that emotion is not a unitary construct but rather a phenomenon organized by different elements, then various aspects of current models of emotion can be considered complementary, rather than contradictory. Second, we advocate that the componential approach to emotion has the potential to become both a consensual and an innovative way to consider the organization of the emotional brain into five functionally defined neural networks (of which the

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precise underlying brain mechanisms remain to be elucidated). Then, we discuss why understanding the brain mechanisms underlying the appraisal component, which can be considered constitutive for the unfolding of the changes in the other components of emotion, may be key to revealing the neural dynamics underlying the emotion process as a whole. Finally, we conclude with some future perspectives and challenges for research on the relationship between emotion and its neural basis in the human brain. This article presents a synthesis integrating and updating our earlier analyses of the existing literature (in particular concerning the component process model [CPM]; Scherer, 1984, 2001; and as published in Brosch & Sander, 2013; Grandjean et al., 2008; Péron, Frühholz, Vérin, & Grandjean, 2013; Sander, 2013; Sander et al., 2005; Scherer, 2009b, 2013) with new affective neuroscience evidence for an appraisal-driven componential approach to the emotional brain.

The Emotion Process and the Complementarity of Current Models of Emotion

Over the last century, a large number of models of emotion have been developed in the affective sciences (see Sander & Scherer, 2009), including adaptational models, appraisal models, basic or discrete emotion models, circuit models, dimensional models, meaning and constructivist models, motivational models, and somatic models. Each of these models captures and explains important facets of the emotion phenomenon. However, it is essential to determine exactly which of the many aspects of the emotion process are highlighted by the respective theories and to what extent they can be mapped onto each other given these aspects.

More important than the disagreements between the different models may be the fact that they are complementary if one examines the way in which they describe different components and phases of the emotion phenomenon (see Scherer, 2000). For instance, one can argue that the two-dimensional valence by arousal space, proposed by Russell (2003) as the basis of his “core affect” model, represents a higher order factor space into which the so-called discrete or basic emotions, as lower order factors, can be projected. Conversely, the basic emotion families (see Ekman, 1992) can be seen as higher order factors with respect to the highly variable outcomes of appraisal processes and the categorization process leading to a specific emotion. Thus, righteous anger because of a norm violation, a slight irritation because of a minor oversight, or blind rage following a physical attack are all members of the anger family, even though their appraisal profiles, intensities, and accompanying action tendencies are somewhat different.

To account for the existence of a limited number of such families, Scherer (1994) has suggested the concept of *modal emotions*, defined as frequently occurring patterns of appraisal of universally encountered events such as sadness in the case of loss or anger in the case of blocked goals. All the members of an emotion family share some but not all distinctive appraisal patterns, which may also be the case for the response pattern. These

common elements account for the fact that languages group these states together using a single label, partly because their occurrence probability is higher than other kinds of states. One may need to go to an even lower level to identify individual emotion family members that share common appraisal profiles (characterized by brief expressions such as “righteous anger”). The lowest level might consist of the continuous adaptational changes that—according to the CPM—are produced by single appraisals. Some examples of these changes are the startle reflex as well as defense and orienting responses, which may be a part of a higher order emotion such as surprise or fear.

All the models proposed highlight important aspects of emotion processes, either with respect to the phase of the process or the nature of the particular components involved. A particular model’s utility depends on its potential contribution to the hypothesis-guided research on the underlying causal mechanisms. In Table 1, we describe different levels as well as the principles that seem to underlie the grouping of lower order units on a higher level. In the context of the current special section on the relationship between emotion and its neural basis, it is interesting to examine the different neural mechanisms that are associated with different theories, and to what extent they can be hierarchically mapped onto each other (see Table 1). For this purpose, it would be highly desirable for theorists and researchers in psychology and neuroscience to identify which of the respective levels they are addressing. By specifying the precise hypothetical construct, component, phase of the emotion episode addressed, and presumed underlying mechanisms it may be possible to achieve a higher degree of scientific integration and replication than has been obtained so far. For example, what are the brain mechanisms that define a specific “core affect” (or a “conceptual act”) and how do they explain its emergence? It should be kept in mind that higher order factors necessarily lose information present in the lower levels, but can also add some “top-down” information not represented at the lower level, such as the explicit categorization process of emotion (e.g., the felt experience). Thus, the high level “core affect” notion treats the valence dimension in a homogeneous fashion, presumably assuming uniform neural processes and physiological manifestations. In contrast, appraisal approaches, in particular the CPM, postulate different types of valence appraisals with different neural and physiological underpinnings (Shuman, Sander, & Scherer, 2013), which is consistent with the recent proposal that hierarchical brain systems support multiple valence representations (Man, Nohlen, Melo, & Cunningham, 2017).

Despite some disagreements between different theories of emotion concerning the involved mechanisms and relevant levels of analysis, can we identify a minimal consensus? In what follows, we argue that there is indeed consensus with respect to the componential nature of the emotion process.

The Multicomponential Nature of the Emotional Brain: Five Emotion Networks

A review of recent major models of emotion indicates that there is a consensus with respect to the notion that an emotion is not a

Table 1. The hierarchical structure of different emotion theories or concepts and their explanatory constructs (from higher to lower levels; adapted and extended from Scherer & Peper, 2001).

Examples of major families of emotion theories	Examples of focal concepts or mechanisms	Rationale and/or basis for higher order projection	Examples of suggested neural mechanisms
Basic or discrete emotion theories (Ekman, 1992; Izard, 1992; Tomkins, 1962).	A small number of “fundamental” emotions such as anger, fear, sadness, joy, disgust, or surprise.	Prototypicality of appraisal, motivational consequences, and response patterns; shared across cultures.	The insula for disgust; the amygdala for fear (see Calder, Lawrence, & Young, 2001; Vytal & Hamann, 2010).
Dimensional theories (Osgood, Suci, & Tannenbaum, 1957; Russell, 1980; Schlosberg, 1952; Thayer, 1989; Watson & Tellegen, 1985; Wundt, 1896).	Valence (positive/negative), activity/arousal (active/passive), approach/withdrawal, dominance/control.	Projection of similarity structures into higher dimensional space.	The mesolimbic system and the orbito-frontal cortex for valence; the reticular formation and the amygdala for arousal (see Hamann, 2012; Posner, Russell, & Peterson, 2005).
Appraisal theories (Lazarus, 1968; Roseman, 1991; Scherer, 1984; C. A. Smith & Ellsworth, 1985).	Specific appraisal processes driving response configurations for events/situations and yielding differentiated emotions.	Temporal coordination of different response systems for a limited period of time as produced by a specific appraisal pattern.	The amygdala as the core of the neural network involved in the appraisal of concern relevance (see Brosch & Sander, 2013; Sander, Grafman, & Zalla, 2003).
Adaptational and neurophysiological theories (Lang & Bradley, 2010; Panksepp, 1998).	Brain systems for seeking, rage, fear, lust, care, grief, and play. Orienting reflex, appetitive and defensive reflexes, startle reflex, sympathetic arousal.	Basic, phylogenetically continuous adaptation and reaction preparation of the organism.	Specific brain networks for primitive affective systems; for instance, the seeking circuit corresponds to the extensive medial forebrain bundle and major dopamine-driven, self-stimulation “reward” circuitry (from ventral midbrain to nucleus accumbens and medial frontal cortex; see Lang & Bradley, 2010; Panksepp, 2010).
Constructivist theories (Averill, 1980; Barrett, 2006; Russell, 2003; Schachter & Singer, 1962).	Any type of categorization or verbal labeling of felt experiences.	Conceptual or meaning space for subjective experience and verbal labels, as influenced by culture, language, personal history, semantic ability, or context.	Regions in the medial posterior part of the brain and in the medial prefrontal cortex for the conceptualization process; anterior cortical midline structures for the experience of a feeling (see Heinzel, Moerth, & Northoff, 2010; Lindquist et al., 2012).

Note. Models vary with respect to the different phases in the emotion process on which they focus (e.g., low-level event evaluation, high-level event evaluation, goal/need priority setting, examining action alternatives, behavior preparation, behavior execution, communication of experiences and sharing them with others; see Scherer, 2009a, for a detailed review).

unitary entity but rather a multicomponent phenomenon (see Sander, 2013). This idea—that emotion is multicomponential—is not particularly new (e.g., Irons, 1897; see also Kleinginna & Kleinginna, 1981, pp. 368–374), and has in the last decades become increasingly agreed upon among the most current emotion theories as shown by their frequent references to some or to all the components. Figure 1 describes the mechanisms suggested to correspond to the five components that compose the two parts of an emotion, namely *emotion elicitation* and the *emotional response*.

To our knowledge, all appraisal theories of emotion agree with the idea that emotions are multicomponential phenomena, and this aspect is particularly essential to the CPM of emotion proposed by Scherer (1984, 2009b), according to whom “The components of an emotion episode are the respective states of the five subsystems and the process consists of the coordinated changes over time” (Scherer, 2005, p. 697). This proposal ties the evolutionary functions of emotion to five organismic subsystems: the information processing (elicitation through appraisal), the support (regulation through autonomic reactions), the executive (motivational action tendencies), the action (expressive

behavior), and the monitoring (feeling) systems. Importantly, as a representative of another major tradition—the circumplex/bidimensional (valence and arousal) theories of emotion—Russell (2009, p. 1259) also emphasized the concept of “components” when describing that a psychological construction produces “a particular emotional episode’s ‘components’ (such as facial movement, vocal tone, peripheral nervous system change, appraisal, attribution, behaviour, subjective experience, and emotion regulation).” Moreover, the very notion according to which an emotional episode is formed by various components is also present in basic emotion theories. Indeed, Matsumoto and Ekman (2009, p. 69), representing basic emotion theories, underlined that “A match, however, initiates a group of responses, including expressive behaviour, physiology, cognitions, and subjective experience. . . . In our view, the term ‘emotion’ is a metaphor that refers to this group of coordinated responses.”

Therefore, taken together, it seems to us that there is consensus among major theories of emotion that the many facets of emotion can be grouped into five components. However, there are many debates concerning the functional relationships between these five components: (a) elicitation, (b) expression,

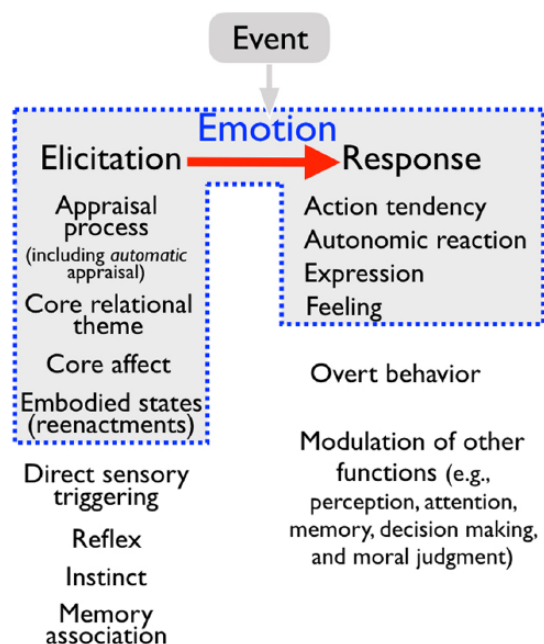


Figure 1. Mechanisms suggested to correspond to the two parts of an emotion are highlighted with a grey background: emotion elicitation and emotional response. (Figure adapted from Sander, 2013).

Note. Effects of emotion on behavior and on other psychological functions are also represented. Dashed lines surrounding some mechanisms indicate that they are considered in some theories to be part of the emotion process. Sander (2013) proposed the following analogy between emotion and memory in order to consider that emotion elicitation is not a mere antecedent to emotion, but is rather constitutive of it. Whereas memory could easily be considered as corresponding mainly to remembering, most contemporary models of memory acknowledge that there is more to memory than what is actually remembered: There are also encoding and consolidating mechanisms. Although the process of encoding could easily be seen as separate from—and antecedent to—memory, it is typically considered as constitutive of it. Taking into account this analogy, elicitation is to emotion what encoding is to memory: its first constitutive step.

(c) autonomic reaction, (d) action tendency, and (e) feeling. In this section, we aim at presenting each of the components (ordered by the facility of transitions between sections) in terms of five functionally defined brain networks, the precise underlying neural mechanisms of which remain to be elucidated. As depicted in Figure 1, while the appraisal process is typically considered to be the component responsible for *emotion elicitation*, the other components are generally thought to reflect the *emotional response*. Such a functional segmentation of the emotional brain is consistent with the recently proposed consensual definition of an emotion (Sander, 2013), suggesting that an emotional episode is an event-focused, two-step, fast process consisting of (a) relevance-based elicitation mechanisms that (b) shape multiple responses (i.e., action tendency, autonomic reaction, expression, and feeling). A key aspect of the componential perspective is the notion of synchronization or pattern organization across the five components, resulting in an emergent feeling. Theoretically, this concept of synchronization/pattern organization is crucial in the distinction of the different

kinds of modal emotions (or basic emotions). We have argued that a specific pattern of modulation across the five components represents a specific emotion's signature, which can sometimes be conceptualized as a consciously experienced and verbally expressed feeling (Grandjean et al., 2008). We have suggested that such pattern organization may rely on neuronal synchronization, which is necessary to link (a) the different neuronal populations involved in the processing of each component (within-component synchronization), and (b) the distant brain networks involved in each component during the emotional episode (between-component synchronization). This approach builds on Fries's (2005) Communication Through Coherence model, which suggests that to communicate, different neuronal assemblies have to be in phase synchronization (e.g., for a specific frequency band such as the theta or alpha band between the amygdala and orbito-frontal regions) or in cross-frequency synchronization (e.g., the theta phase in a specific region such as the amygdala, organizing the gamma bursts in another brain region such as the ventro-medial prefrontal cortex [vmPFC]) to allow the exchange of information between distant brain regions. Synchronization of neuronal activity can take place at different levels including close neuronal assemblies interacting at high frequencies, and more distant regions synchronized at lower frequencies (see Grandjean et al., 2008).

The Expression Network

Expressions of emotions have been extensively studied, in particular facial expression but also vocal expression, body movement, gesture, or posture, and, to a lesser extent, bodily odors. As most studies have focused on the *perception* of facial expressions of emotion, only little is known about the brain mechanisms responsible for the *production* of facial expressions (but see Morecraft, Stilwell-Morecraft, & Rossing, 2004; Rinn, 1984). Evidence from brain-damaged patients has suggested the existence of a double dissociation, with voluntary expressions depending on cortical structures and spontaneous expressions depending on subcortical structures; however, other studies have indicated that areas of the cingulate cortex may also be relevant for spontaneous facial movements (see Korb & Sander, 2009).

We think that it is important to dissociate different levels within all of the components. Three levels can be considered in the expression component (see Graybiel, 2008): first, a reflex-like level; second, an overlearned habitual motor response or motor habit level; and finally, a voluntary goal-oriented level. Usually all three levels interact, forming an observed behavior during an emotional episode composed of the modulations of facial and vocal expressions, global body movement, gestures, and posture. Reflex-like responses (such as screaming during the appraisal of a sudden threat) are thought to be implemented in subcortical and brainstem neural structures (e.g., the pons), and to be difficult to inhibit. In the domain of vocalization, it has been shown that the periaqueductal grey area (PAG) is a crucial structure for the generation of screams (e.g., Davis, Zhang, Winkworth, & Bandler, 1996; Holstege, 2014), which is already

present at a very early stage of life, possibly even at birth. More complex, often overlearned, motor patterns involving a learning process, such as the contextual modulation of an emotional facial expression, are implemented in complex neuronal functional networks, including the different basal ganglia and premotor and motor cortical areas. Such expressive motor habits, which can be developed during the first years of life, are progressively learned through a chunking process and a progressive neuronal shift, that is, the neurons firing for a specific series of chunked behaviors from anterior areas to posterior regions at the motor cortical level and in the basal ganglia (see e.g., Graybiel, 2008). This progressive posterior functional neuronal shift is essential to the progressive automatization of behavior, especially for its motor aspect, though it is not restricted to it (Péron et al., 2013). The third level, the most highly controlled one, is likely to be organized in the form of a series of functional neuronal networks, including different frontal areas (e.g., the dorso-lateral prefrontal cortex [DLPFC]) as well as motor subcortical and cortical areas, which are essential, for example, to control and plan expressions. The distinction between these three different levels is not supposed to be absolute but rather continuous. In fact, the brain stem, subcortical, and cortical structures are generally interacting in complex ways to produce a specific motor expression pattern. Each motor pattern is thought to be characterized by a specific weighted contribution from each level (from automatized to controlled modes). It is also important to mention that they can be subject to reciprocal inhibition; for instance, the hyperdirect pathway between the subthalamic nucleus—one of the most frequently studied structures of the basal ganglia—and the frontal areas is essential in the inhibition of prepotent responses to shift into a more controlled behavior. This is the case, for example, when people, after initially expressing surprise as a reflex-like or overlearned defensive automatic response, realize that this reaction is not adapted to the current situation and express another, more controlled facial expression such as a smile (e.g., a friend surprising you from behind in the street; see Benis et al., 2016; Péron et al., 2013). Of course, such organized patterns—through the chunking process in behavior automatization/overlearned patterning—are not restricted to motor aspects but have also been suggested to occur for other brain mechanisms (e.g., mental habits; see Graybiel, 2008).

The Action Tendency Network

In his theory of emotion, Dewey (1895, p. 17) considered emotions to imply “a readiness to act in certain ways” and suggested “anger means a tendency to explode in a sudden attack, not a mere state of feeling.” An *action tendency* describes the internal motive states that are hypothesized to underlie a felt urge, the felt direction of that urge (e.g., toward or away from), and the “aboutness” of that urge (Frijda, 2009). Such action tendencies (e.g., approach, avoidance, being with, interrupting, dominating, submitting) are also thought to underlie overt behavior such as running away or physically approaching a stimulus (Frijda, 2009). During an emotional episode, some action tendencies with control precedence take priority over other potential action

tendencies (Frijda, 1986; Scarantino, 2018). In affective neuroscience, two classic opposing action tendencies have been the focus of much research: approach versus withdrawal. For instance, Davidson and Sutton (1995, p. 220) proposed the anterior brain asymmetry model, and summarized early findings as follows:

In general, negative affect (e.g., disgust or fear) accompanied by withdrawal reactions, such as turning away from the stimulus or fleeing, has been found to increase right-sided anterior activation (in both prefrontal and anterior temporal scalp regions), whereas positive affect associated with approach reactions, such as reaching out toward another person, increases left-sided activation in these regions.

Since these first pieces of evidence, results have been less consistent in general, specifically taking into account fMRI studies; however, a recent literature review highlighted that much research has been obtained in favor of the hypothesis that greater left than right frontal cortical activity is associated with approach motivation (Harmon-Jones & Gable, 2018). Nonetheless, Harmon-Jones and Gable conclude that the other key hypothesis of the brain asymmetry model (i.e., the hypothesis that greater right than left frontal cortical activity is associated with withdrawal motivation), although supported, needs to be further investigated in order to be able to draw a conclusion.

It should be noted that the hemispheric lateralization of approach versus avoidance action tendencies may be related to the kinds of movements that are necessary to achieve a specific proximal or distal goal. Actual approach-related movements typically necessitate more fine-grained motor control compared to avoidance-related movements; therefore, approach-related movements are typically achieved with one's dominant hand. For example, it has been shown that participants' trait approach motivational tendencies (approach vs. avoidant) preferentially engage left cortical areas in right handers, while it is the opposite for left handers (Brookshire & Casasanto, 2012). Of course, during an emotional episode, the production of action tendencies (and actual movements) is not only implemented in the left and right prefrontal cortex (PFC). The anatomical substrates subserving emotional effects on action preparation are still poorly understood, but recent research has made significant advances. Using diffusion tensor imaging in humans, Grèzes, Valabrègue, Gholipour, and Chevallier (2014) provided evidence for a structural connection between the amygdala and motor-related areas (the lateral and medial precentral, the motor cingulate, and the primary motor cortices, as well as the postcentral gyrus). The authors highlighted that such a direct amygdala–motor pathway might offer a mechanism by which the amygdala can influence more complex motor behaviors. Reviewing neuroimaging studies on how emotion influences voluntary action, Blakemore and Vuilleumier (2017) revealed several structures involved in emotional-motor processing, in particular the PFC, including the right inferior gyrus (rIFG), the supplementary motor area (SMA), the anterior cingulate cortex (ACC), as well as the amygdala, the PAG, and the basal ganglia. As discussed by Péron et al. (2013), the basal ganglia (the striatum, the pallidum, the substantia nigra, and the subthalamic nucleus) are among the most important

subcortical structures involved in motor preparation and actual motor actions. They are also crucial for overlearned complex motor patterns (see The Expression Network section). Because each of these regions is characterized by three different territories (motor, associative, and limbic) corresponding with three different patterns of cortical–subcortical connectivity, we have proposed that these regions are crucial for the integration of action tendencies and motor patterning related to emotional processes (Péron et al., 2013).

The Autonomic Reaction Network

The pioneering James–Lange theory was extremely influential on research in affective neuroscience, in particular with respect to the historical idea that bodily changes may be primary to other emotional components. This perspective gave rise to neo-Jamesian theories of emotion (e.g., Damasio, 1998; Prinz, 2004). According to Damasio, many brain systems have been proposed to be involved in the production and in the representation of an “emotional body state.” The visceral sensory pathways and brain centers are starting to be well elucidated, and subcortical as well as cortical (e.g., primary somatosensory cortex [SI], secondary somatosensory cortex [SII], and the insular cortex) somatosensory maps have been attributed the critical role of representing the bodily response (see Critchley & Harrison, 2013; Damasio, 1998). For example, the right insular cortex and the PFC seem especially important for the subjective detection of heartbeat modulations and the related self-reported anxiety (Critchley, Wiens, Rotshtein, Ohman, & Dolan, 2004). Importantly, current models of emotion do not argue that the bodily reaction always needs to occur within the body itself in order to be a component of emotion: the cerebral bodily map representation would be sufficient (e.g., an “as-if body loop” in Damasio’s model), as it has been suggested by embodiment theories of emotion.

Research concerning the existence of *emotion-specific* bodily reactions, mostly measured by the effects of emotions on the autonomic nervous system, is not conclusive (for reviews, see Cacioppo, Berntson, Larsen, Poehlmann, & Ito, 2000; Kreibitz, 2010). A key question regarding embodiment and, more generally, the bodily reaction in emotion, concerns its very nature. Does this reaction correspond to specific patterns of bodily changes associated with particular situations, or rather to general arousal that is contextually interpreted? Jamesian and basic emotion theories speak in favor of the existence of specific patterns, at least for some emotions (e.g., for “standard emotions,” James, 1884; or for “basic emotions,” see Levenson, 2011). Many theories have the tendency to use the general construct of “arousal” to refer to the bodily reaction during an emotion. Although the concept of arousal is indeed tightly linked to bodily reactions, it is in fact a much wider construct used for research not only on emotion, but also on attention, performance, memory, and personality (for review, see Sander, 2013). Despite the fact that the usefulness of this notion of a general arousal system has been strongly challenged over the years (see Neiss, 1988; Robbins, 1997), it is still one of the most widely used constructs in affective neuroscience.

We also emphasize that the measure of bodily reactions—and its interpretation—in the context of emotion is particularly complex due to several factors, including, especially, the partial decoupling between the actual bodily changes (using e.g., skin conductance, heartbeat, respiration, visceral reactions) and the sensitivity of the subjective perception of such bodily changes during an emotional episode due to interindividual differences. Thus, people can be differentially influenced by their bodily reactions as a function of their sensitivity to such information. Another factor, highlighted by Stemmler and collaborators (see Stemmler, 1989; Stemmler & Wacker, 2010), refers to the interindividual sensitivity differences to the *context* impacting physiological reactions during an event eliciting an emotional episode. Finally, the interindividual response specificity, or the preferred channel of body reactions (e.g., cardiac, perspiration), also needs to be taken into account in research testing the hypothesis of body reactions and emotion specificities.

The Feeling Network

Until the beginning of the 20th century, most theories of emotion (e.g., those of James and Wundt) were in fact theories of *feeling* (i.e., emotional experience). Even today, many theories equate emotion with feeling, but major efforts have been made to distinguish the two (see Reisenzein & Döring, 2009).

Some regions of the brain have been particularly linked to the feeling component of emotion. For instance, SII has been proposed to be a neuroanatomical correlate of the “emotion percept” concept (Koelsch et al., 2015), a preverbal form of subjective feeling. Other regions such as the anterior cortical midline structures (Heinzel et al., 2010) and the anterior insular cortex (Gu, Hof, Friston, & Fan, 2013) have also been suggested to be key regions subserving feelings. Most of the conceptualizations of the feeling component in the literature are based on a dimensional perspective. For instance, Posner et al. (2005) relied on Russell’s core affect model in suggesting that “all affective states arise from two fundamental neurophysiological systems, one related to valence (a pleasure–displeasure continuum) and the other to arousal, or alertness” (Posner et al., 2005, p. 716). According to these authors, these two neurophysiological systems are independent and largely subserved by subcortical structures. In particular, the authors concluded that the mesolimbic system may “represent a neural substrate for the valence dimension proposed by the circumplex model of affect” (Posner et al., 2005, p. 722). With respect to the “arousal network” pathways, the authors highlighted the critical role of the reticular formation that, in particular, receives information from the amygdaloreticular pathways. They proposed an integrated representation of the activity within these two neurophysiological systems—valence and arousal—as the basis for a conscious emotion experience.

However, as discussed earlier, the notion of a unitary arousal dimension has been seriously challenged. Similarly, the notion of a unitary valence dimension has been subject of debate (for review, see Man et al., 2017; Shuman et al., 2013). There is an

enormous amount of empirical evidence that valence and arousal can be considered stable higher order projections of more diverse small-scale phenomena, as pointed out in the introduction (see reviews in Kuppens, Tuerlinckx, Russell, & Barrett, 2013; Scherer, Dan, & Flykt, 2006). However, this does not, in itself, justify the assumption that these also have clear-cut, homogenous neural footprints. Similarly, although the two dimensions—valence and arousal—are often proposed as building blocks of the phenomenology of emotions, many authors from different theoretical backgrounds have suggested that a feeling is shaped by felt action tendencies, felt motor expressions, and felt bodily reactions (for review, see Sander, 2013). Consistently, Panksepp (2005, p. 32) considered that “primary-process affective consciousness emerges from large-scale neurodynamics of a variety of emotional systems that coordinate instinctual emotional actions.” Likewise, Thagard and Aubie (2008, p. 811) argued that “conscious emotional experience is produced by the brain as the result of many interacting brain areas coordinated in working memory.” Scherer (2009b, pp. 1318–1321) has suggested that feeling is dependent on the processes’ degree of synchronization in the other components surpassing a certain threshold (see Dan Gläuser & Scherer, 2008).

Correspondingly, from our perspective, feeling is an emergent phenomenon involving a series of complex neural dynamics between distributed brain regions. We distinguish several aspects in this perspective. The first one refers to the neuronal dynamics at a local scale, for example, within the insula, for the integration of different aspects of bodily reactions represented in different neuronal subpopulations (e.g., cardiac, respiratory; with respect to the study of intrasubcortical functional connectivity in humans, see e.g., Almashaikhi et al., 2014). The second one concerns the neuronal dynamics at a more distant scale: the integration of somatosensory representations (SI and SII) and the information from the insular cortex would involve transient neuronal synchronization between these regions and the PFC to be able to represent, at least partly, such modulations in working memory (with respect to connections between the insula and other regions, see e.g., Allen et al., 2016). The *valuation* of these somatic modulation representations—taking into account the represented context in which such bodily reactions are elicited—is thought to particularly involve the vmPFC.

A possible last step consists of conceptual activity—the explicit categorization and verbal labeling of the feeling. However, this is an optional step, and possibly rather rare as there is good evidence that people often have feelings, especially mixed feelings, that they find difficult to categorize and even more so, to label explicitly. In terms of neural mechanisms, the inferior frontal cortex would be an excellent candidate for such complex invariant detection related to verbal labeling (Frühholz & Grandjean, 2013). Future research needs to test these hypotheses using methods combining excellent resolutions at the spatial and temporal scales such as intracranial recordings in a human clinical population (see e.g., Murray, Brosch, & Sander, 2014) or combining magnetoencephalography with intracranial recordings.

The Elicitation Network

As suggested in Figure 1, there is more to emotion than the emotional response, in particular, the underlying causal structure, the elicitation mechanism. This is not a one-way street—the existence of a feedback loop has been suggested between the emotion response and emotion elicitation (see Sander et al., 2005). However, in order to propose models that account for the full emotion episode, it is crucial to consider the existence of causal mechanisms that lawfully drive changes in the response components.

Although our perspective focuses on appraisal processes (including automatic or overlearned appraisals; see Leventhal & Scherer, 1987) as major determinants of emotion elicitation, there may well be other mechanisms involved (see Figure 1). Indeed, some models suggest that core relational themes, core affects, embodied states, direct sensory triggering, reflexes, instincts, or memory associations can elicit emotions (for a detailed presentation, see Sander, 2013). However, there seems to be consensus that for stimuli to be categorized as “emotional stimuli,” they need to have high relevance to the observer’s survival and well-being (see Brosch, Pourtois, & Sander, 2010). For instance, as LeDoux (1989, p. 267) puts it, “The core of the emotional system is a network that evaluates (computes) the biological significance of stimuli.” The notion of *relevance* captures the evolutionary significance dimension but also refers to other types of concerns. For instance, Frijda (1986, 2007) has proposed that emotions are elicited by events that are relevant to major *concerns* of an individual. Concerns are psychological representations that underlie or overlap with other motivational constructs such as needs, goals, desires, and values. Broadly defined, a concern is a disposition to desire the occurrence or nonoccurrence of a given kind of situation.

Whether a theory refers to stimulus significance primarily in terms of (a) pleasure and arousal (e.g., Bradley, 2009); (b) biological and evolutionary considerations (e.g., LeDoux, 1989; Öhman & Mineka, 2001); (c) primary appraisal (e.g., Lazarus, 1991); (d) dynamics of appraisal checks (e.g., Scherer, 2009b); or (e) concerns (e.g., Frijda, 2007), there seems to be consensus that emotions need to have objects that the organism, at some level, considers *relevant*—even if this relevance is not always explicitly accessible to the subject.

So far, targeted research directly aiming at identifying the brain areas *dedicated* to the emotion elicitation network is largely lacking. Although it is not an emotion network as such, the so-called “salience network,” an intrinsically connected large-scale network, has often been studied in relation to the emotional brain. This network has been suggested to be involved in the detection of several types of salient events, including emotional stimuli, and is composed of the anterior insula, the dorsal ACC, the amygdala, the ventral striatum, and the substantia nigra/ventral tegmental area (Menon, 2015). Recently, in a model aimed at explaining placebo effects, Ashar, Chang, and Wager (2017) suggested that regions of the default mode network, in particular the vmPFC, the posterior cingulate cortex,

and the inferior temporo-parietal junction (TPJ), are involved when individuals evaluate their future well-being and the personal significance of their symptoms.

We have argued that a consensual definition of relevance detection that considers both the notions of “biological significance” (e.g., LeDoux, 1989) and of “primary appraisals” (e.g., Lazarus, 1991) would consider that an object or situation is relevant for an individual if it increases the probability of satisfaction or prejudice toward the individual’s major concerns (see Sander, 2013). In particular, we have argued that the amygdala is the core of the brain network involved in relevance detection (Sander et al., 2003; see also Pessoa, 2010; Pessoa & Adolphs, 2010), with specific neural networks being certainly differentially involved in different types of affective relevance (e.g., need relevance, goal relevance, and value-based relevance). Research should consider the role of the amygdala within various large-scale functional brain networks (see e.g., Pessoa, 2017). For instance, in addition to the amygdala, various brain structures are involved in the valuation process (e.g., the ventral striatum and the vmPFC).

The Appraising Brain

The cognitive revolution has had a major impact on theories of emotion, particularly with respect to two major points: (a) the cognitive mechanisms underlying the emotion elicitation process (*appraisal processes*), and (b) the process underlying emotion categorization (typically involved in the *labeling* of the feeling). In this framework, theories interested in emotion elicitation have developed models of appraisal processes (e.g., core relational themes or appraisal criteria approaches), whereas theories interested in labeling have developed models of categorization (e.g., Schachter and Singer’s theory of emotion, or core affect approaches). Such cognitive approaches to emotion allowed building bridges between the field of cognitive neuroscience and the field of affective neuroscience (see Sander, 2013).

Figure 2 illustrates a functional architecture of emotion in which the emotion networks and their interactions are described (based on appraisal theory, more particularly the CPM proposed by Scherer, 1984, 2009b; see also Grandjean et al., 2008; Sander et al., 2005).

A conceptual strength of appraisal theories in many research groups worldwide is to argue that the emotion process is driven by the results of the evaluation of a series of major appraisal objectives. It is important to mention that according to such theories, not all “cognitions” or “thinking processes” are considered an emotion-eliciting appraisal. In this respect, appraisal theories are fairly different from those theories that simply mention cognition may play a role in emotion. More precisely, there are some specific appraisal criteria that have been studied and linked to emotional responses (see e.g., Ellsworth & Scherer, 2003). Such appraisals include the following ones: How relevant is this event for me?; Does it directly affect my social reference group or me? (goal relevance); What are the

implications or consequences of this event and how do these affect my well-being and my immediate or long-term goals? (goal congruence); Did I expect this event and its consequences and how certain are they (novelty, expectation, certainty); Who caused this event, am I responsible or someone else? (agency, causation); How well can I cope with or adjust to these consequences? (coping potential, control, power). While the importance of these appraisal dimensions is largely consensual among appraisal theorists, some authors add more dimensions such as the event’s intrinsic pleasantness and its compatibility with respect to self-concept, social norms, and values. For a more detailed overview of suggested appraisal criteria, the reader is referred to the special section published in *Emotion Review* on appraisal theories (see Moors, Ellsworth, Scherer, & Frijda, 2013). While earlier work on appraisal has been criticized for its reliance on self-reports, empirical research on appraisal processes has evolved in the sense that researchers increasingly manipulate appraisal variables in real or simulated environments instead of measuring them, which is a way to go beyond correlations (see following lines for several examples). Moreover, effects of appraisal processes on the emotional response are also increasingly measured by changes in the components of expression, action tendency, and autonomic response, rather than only by changes in the emotion labels (see Moors, in press).

Brosch and Sander (2013) reviewed neuroimaging studies in humans, and suggested some neural mechanisms that may subserve the processing of major criteria proposed by appraisal theorists. Specifically, the authors associated (a) novelty processing with a neural network centered on medial temporal regions such as the hippocampus and the amygdala, extending to the lateral and orbital PFC and the temporo-parietal cortex; (b) concern relevance processing with a neural network centered on the amygdala; (c) goal congruence processing with a neural network centered on the ACC, and the DLPFC; (d) agency processing with a neural network centered on the TPJ, the precuneus, the dorsomedial PFC, the pre-SMA, the insula, and the motor-specific regions; and (e) compatibility with norms and values processing with a neural network centered on the superior anterior temporal lobe, the medial PFC, the amygdala, the dorsal striatum, and the DLPFC.

Recently, R. Smith and Lane (2015) adopted such an appraisal perspective to suggest a neuro-cognitive framework of both conscious and unconscious emotional processes. In their model, hierarchical emotion generation is realized by means of appraisal mechanisms requiring differing amounts of processing time and cognitive/computational sophistication (R. Smith & Lane, 2015, p. 6, Figure 1). Additionally, Skerry and Saxe (2015) used fMRI and advanced analyses to investigate how appraisal criteria can help to better understand the organization of neural representations of emotion. They showed that the appraisal space performed reliably better than the circumplex space and the basic emotion space in order to predict emotion discrimination in several regions of the brain, including the dorsal and middle medial PFC.

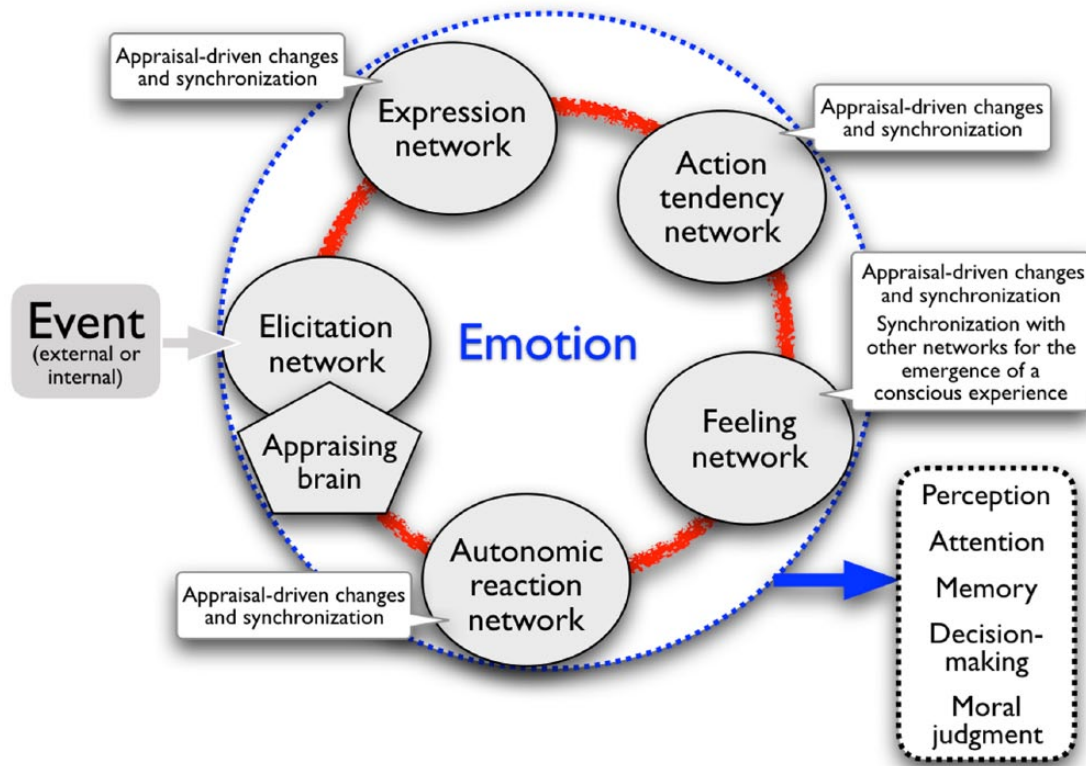


Figure 2. This figure illustrates the appraisal-driven componential approach to the emotional brain.

Note. According to this approach, the emotional brain consists of five complementary and interrelated brain networks: (a) the elicitation network, (b) the expression network, (c) the autonomic reaction network, (d) the action tendency network, and (e) the feeling network. Such an approach also considers that the appraisal of an internal or external event (1) is causal in emotion elicitation; (2) is constitutive of (not only antecedent to) emotion (i.e., the combination of appraisal outputs is key for the emotional experience); and (3) determines the response profiles of changes and synchronization in the other components.

In addition to research on the cerebral basis of emotion in terms of brain structures involved, some specific hypotheses derived from appraisal models, in particular the CPM, have been tested using electroencephalography (EEG) and other psychophysiological measures (see Sander, 2013; Scherer, 2009b). For instance, EEG has been used to investigate the appraisal processes' temporal dynamics, and results suggest that different appraisal checks have specific brain state correlates that occur rapidly. In particular, Grandjean and Scherer (2008) manipulated three appraisal processes (novelty, intrinsic pleasantness, and goal conduciveness) and obtained results with topographical and wavelet analyses suggesting that the effects of these processes occur in a sequential rather than parallel fashion. Van Peer, Grandjean, and Scherer (2014) replicated and extended these results, as did Gentsch, Grandjean, and Scherer (2015) who extended this approach by adding the coping potential check, predicted to occur after the goal conduciveness check. Taken together, these studies provide increasing empirical evidence for the predicted sequential processing of novelty, intrinsic pleasantness, goal conduciveness, and coping potential. Furthermore, using other measures than EEG has led to consistent results. For instance, Lanctôt and Hess (2007) found that facial reactions to an intrinsic pleasantness manipulation were

faster than facial reactions to a goal conduciveness manipulation. Regarding autonomic physiology, Delplanque et al. (2009) observed that effects on heart rate occurred earlier in response to novelty detection than in response to a pleasantness manipulation. More broadly, a series of experimental studies showed the efferent effects of the manipulation of appraisal checks on somatovisceral changes and motor expression as markers of appraisal results (Aue, Flykt, & Scherer, 2007; Aue & Scherer, 2008; Johnstone, van Reekum, Hird, Kirsner, & Scherer, 2005; van Reekum et al., 2004). Altogether, electromyography measures, as well as autonomic nervous system measures, provide evidence for the specificity of the efferent physiological effects of particular appraisal check combinations (for review, see Scherer, 2009b, 2013).

The study of appraisal processes is also a meeting point between affective neuroscience and social neuroscience. Indeed, emotions are very often elicited by social cognitions, and produce social behaviors. For instance, the study of social appraisal, which is the idea that "Behaviors, thoughts, or feelings of one or more other persons in the emotional situation are appraised in addition to the appraisal of the event per se" (see Manstead & Fischer, 2001, p. 222), represents an important avenue for future research in social and affective neuroscience.

Conclusion

Considering some of the major families of emotion theories (see Table 1), our article aimed at highlighting appraisal theories of emotion by showing their specificities (but also their shared assumptions) with respect to other major theories of emotion. Considering the various perspectives, we specifically proposed that it might be useful for affective neuroscience to consider an appraisal-driven componential approach to the emotional brain. It seems to us that this approach brings two particularly original foci to current affective neuroscience research.

First, endorsing the componential approach (which is apparently quite consensual for major models of emotion) has led us to suggest that the emotional brain consists of five complementary and interrelated brain networks: (a) the elicitation network, (b) the expression network, (c) the autonomic reaction network, (d) the action tendency network, and (e) the feeling network. Although brain research has been concerned with each of these components, it has rarely been developed in the context of an integrated approach to emotion. Consequently, brain data are still missing for these networks that are mainly functionally defined so far. It is a major challenge to outline the cerebral architecture of these networks, and how they interact and synchronize. If we succeed in this endeavor, it will allow the field to test questions such as whether the brain implements modules for basic emotions or whether all emotions emerge from covariations of these distributed five brain networks, with some modal emotions corresponding to particularly frequent patterns of synchronizations.

Second, our approach emphasizes the suggested causal role of the “appraising brain” in the elicitation network as a driver of changes and synchronization in the four other networks. Experimental studies on appraisal processes have existed for more than 50 years in psychology, and the appraisal theory of emotion has arguably become one of the major theories in affective sciences. Recently, it has been suggested that appraisal theory is the most influential theory within affective computing (Gratch, Cheng, & Marsella, 2015). However, the study of the appraising brain is still relatively new in affective neuroscience. Interestingly, and somewhat paradoxically, thanks to the recent emergence of research on the neurobiological basis of emotion regulation, the cerebral basis of *reappraisal* has been the object of much more intense neuroscience research (see e.g., Kalisch, 2009) compared to the cerebral basis of *appraisal*, despite the fact that the appraisal process is by definition primary to the reappraisal process. Research advances in the understanding of the appraising brain seem very promising as a result of the methodological advances that have been made in the spatial and temporal analysis of brain dynamics (even with fMRI; see e.g., Résibois et al., 2017), as well as with the development of computational approaches in affective neuroscience. More generally, using multivariate pattern analyses and graph analyses to study the functional organization of the emotional brain (see Grosenick, Klingenberg, Katovich, Knutson, & Taylor, 2013; Kragel & LaBar, 2016; Peelen, Atkinson, & Vuilleumier, 2010; Saarimäki et al., 2016; Skerry & Saxe, 2015) may provide new

results linking the appraising brain to the representation of emotion categories in the brain.

Adopting an appraisal-driven componential approach to the emotional brain will also allow asking original questions both *within* and *outside* the emotion networks. We mention some examples of each:

1. Testing the relationships *within* the emotion system allows asking questions concerning the relationships between emotion networks. A long-standing debate in emotion psychology concerns the understanding of *what* is expressed during the production of a so-called expression of emotion (see contributions in Fernández-Dols & Russell, 2017). Using a multicomponential approach enables researchers to test the idea that particular appraisal checks generate facial expression units that can be interpreted as a functional consequence of certain appraisal results (e.g., Scherer & Ellgring, 2007), and that appraisal-based inferences are what subserve emotion recognition in the face (e.g., de Melo, Carnevale, Read, & Gratch, 2014) or in the voice (e.g., Laukka & Elfenbein, 2012). Another long-standing debate, this time in affective neuroscience, concerns the role of bodily reactions in emotion (see previous lines). Using a multicomponential approach allows testing the idea that the autonomic reaction network that represents or simulates bodily reactions is important to drive changes in the feeling network. This would even enable testing the hypothesis that variations in the autonomic reaction network are themselves caused by appraisal processes.
2. Testing effects *outside* the emotion system allows asking original questions on how emotion modulates non-evaluative cognitive processes. Indeed, accumulating evidence indicates that emotion modulates perception, attention, as well as memory (see Koelsch et al., 2015; Pourtois, Schettino, & Vuilleumier, 2013; Vuilleumier, 2015); understanding which component(s) of emotion drives this effect would enable the development of fine-grained models. For instance, further research could test whether amygdala-based emotional effects on perception, attention, and memory could be explained by appraised relevance rather than arousal (see Montagrin & Sander, 2016; Pool, Brosch, Delplanque, & Sander, 2016).

We think that a challenge for future research on the emotional brain will certainly be to go beyond studying the cerebral correlates of specific constructs (e.g., arousal), and to use the full variety of methods offered by affective neuroscience in order to test the functional organization and temporal dynamics of the appraising brain and the other emotion networks.

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The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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